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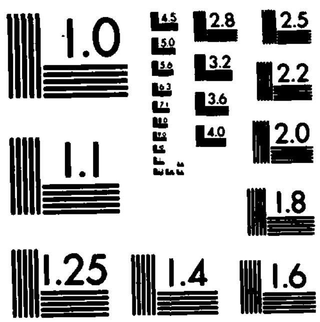

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EXPERIMENTS ON FOCUSING SYSTEMS IN LASER INITIATED DISCHARGE CHANNELS

R. M. Gilgenbach, O. E. Ulrich,
L. Horton, and J. Meachum

Technical Report #106

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Experiments have been performed to compare alternative focusing systems for CO_2 laser initiation of 30 kV discharge channels in atmospheric pressure air. The three focusing systems included: 1) A single focus by means of a 79 cm focal length lens, 2) A single focus by means of a 250 cm focal length mirror, and 3) Dual foci in which the beam was split and both the 79 cm focal length and the 250 cm focal length systems were employed.

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Results show that the long chain of breakdown beads from the 250 cm focal length mirror is effective in initiating and guiding channels up to 10 cm in length, compared to about 5.6 cm for the 79 cm focal length lens. The scaling of channel length with laser energy has been measured to be roughly linear for the 250 cm focal length system; comparison has been made with the distance over which laser induced breakdown occurs.

EXPERIMENTS ON FOCUSING SYSTEMS IN LASER INITIATED DISCHARGE CHANNELS

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ABSTRACT

Experiments have been performed to compare alternative focusing systems for CO_2 laser initiation of 30 kV discharge channels in atmospheric pressure air. The three focusing systems included: 1) A single focus by means of a 79 cm focal length lens, 2) A single focus by means of a 250 cm focal length mirror, and 3) Dual foci in which the beam was split and both the 79 cm focal length and the 250 cm focal length systems were employed. Results show that the long chain of breakdown beads from the 250 cm focal length mirror is effective in initiating and guiding channels up to 10 cm in length, compared to about 5.6 cm for the 79 cm focal length lens. The scaling of channel length with laser energy has been measured to be roughly linear for the 250 cm focal length system; comparison has been made with the distance over which laser induced breakdown occurs.

I. INTRODUCTION

Since the demonstration of the laser triggered spark gap switch[1], a number of investigators have shown that laser induced breakdown can initiate and guide discharge channels with lengths of several m[2-5]. It has been suggested that the reduced density channels from such discharges could transport particle beams in an inertial confinement fusion reactor[6,7]. It would be advantageous for fusion reactors to operate with a high density shielding gas blanket, but with voltages low enough to prevent arcing. While laser guided discharges have been demonstrated at modest voltages (40 kV) in low pressure gas[8], most experiments in atmospheric pressure air have employed voltages of several hundred kV[2-5].

In the experiments reported here, we have investigated and compared several alternative focusing systems for CO_2 laser radiation which have been used to initiate and guide 30 kV discharges in atmospheric pressure air. Since the discharge channel lengths initiated by the laser are well above the interelectrode sparking distance, these experiments are also relevant to spark gap switches and to the reproducible study of artificial lightning at modest voltages.

II. EXPERIMENTAL CONFIGURATION

A schematic illustration of the experiment is depicted in Fig. 1. The high power TEA CO_2 laser, a Lumonics 601A, was operated at a gas mixure which generated a 12 J pulse

with a duration of about 100 ns. A propylene attenuator cell controlled the incident laser power and protected the laser from reflected power. Three focusing systems have been investigated:

1) Single focal spot from a germanium meniscus lens of focal length 79 cm,
2) A single focus from a gold mirror of focal length 250 cm,
3) Dual foci, with the germanium lens focusing the direct beam while the power split off the main beam by a salt wedge is focused by the gold mirror. The three focusing systems are shown schematically in Fig. 2.

The discharge system consisted of a high voltage capacitor , which was discharged through a precision triggered spark gap switch after a preset delay following the laser pulse. This low inductance circuit had a ringing period of about 2.5 μs and a typical peak current of 8-12 kA (at 30 kV charging voltage), depending upon the channel length.

Channel diagnostics included:

1) Voltage,
2) Current,
3) PIN diode to measure temporally resolved optical emission,
4) Filtered photomultiplier tube to measure the spectrally and temporally resolved emission, and

5) Open shutter photography to measure the channel structure.

III. EXPERIMENTAL RESULTS AND DISCUSSION

In the first set of data presented here a comparison was made of the discharge initiation and guiding of the 79 cm f.l. germanium lens versus the 250 cm f.l. gold mirror. These two focusing systems were compared under identical laser and atmospheric conditions during a single experimental run. The incident energy in the laser pulse was measured by means of a large area calorimeter and found to be 6.08 J downstream of the attenuator. Measurements of the laser pulse shape made with a photon drag detector show that for the gas mix employed in these experiments the pulse is triangular with a duration of 100 ns. The energy measurement thus translates to a peak laser power of 0.122 GW. The capacitor voltage for the discharge was 30 kV in the experiments reported here and a 4 μs delay was imposed between the laser pulse and the triggering pulse to the spark gap switch.

Figure 3 compares the laser induced breakdown produced by the two focusing systems. It can be seen from the figure that while the short focal length germanium lens generates the characteristic pear shaped breakdown spark , the longer focal length mirror induced breakdown along a chain of beads, as observed in other experiments[2]. The experimentally observed breakdown lengths can be compared to a simple model for the power density in the focused annular

beam if it is assumed that breakdown occurs before the beam reaches the focal point. Assuming a uniform annular beam profile , the outer and inner annular radii can be expressed approximately for points away from the focal point as:

eq. 1 $$R(d) = R\left(\frac{f-d}{f}\right) \quad (\text{for } f \neq d)$$

where f is the focal length and d is the distance from the mirror or lens. The power density of the beam can then be written:

eq. 2 $$P_d = 1.76\left(\frac{f}{f-d}\right)^2 \ \mathrm{MW/cm^2}$$
$(\text{for } f \neq d)$

where the annular beam dimensions are: R_o=5.5 cm and R_i=2.85 cm, while the peak laser power of 0.122 GW has been assumed. For the clean air breakdown threshold[9] of 3 GW/cm^2 the point at which breakdown is predicted can be expressed :

eq. 3 $$d = f\ (0.976)$$

Thus, for the 79 cm f.l. lens, breakdown is expected to start 1.9 cm before the focal point is reached, whereas for the mirror of f.l. 250 cm the breakdown should begin 6 cm before the focal point is reached. If the laser radiation is able to penetrate the dense breakdown plasma it should be possible to achieve breakdown over a length at least twice the value calculated here. Figure 3 shows that for the 79

cm focal length, most of the laser energy is absorbed on the laser side of the focal spot and the length of the breakdown region (about 2.5 cm) is longer than the predicted value, indicating that dust and aerosols have lowered the breakdown threshold. This behavior can also be interpreted in terms of the optical detonation wave which propagates towards the radiation source. For the 250 cm focal length lens the breakdown extends about 12.5 cm and the breakdown beads appear mainly on the upstream side of the laser focal point.

Discharges initiated by the two focusing systems are compared in Fig. 4. Two major differences were observed in the initiation and guiding of discharges by the different focal length systems. The first and most obvious difference is that the longer focal length system initiated and guided longer channels. In the 250 cm f.l. case the maximum channel length was 10 cm and channels could be reproducably initiated and guided over lengths of 9 cm. For the 79 cm f.l. germanium lens the maximum length of discharge channels was 5.6 cm with reliable initiation of channels 5 cm or less. The second major difference between the two different f.l. systems is that while laser induced breakdown initiates discharges over gaps which would not sparkover without initiation, only for the longer focal length system were the discharges well guided. This is apparently due to the pattern of the laser energy deposition and generation of molecular ions along the chain of breakdown beads. It has been shown in Ref. 3 that if a large number of breakdown

beads are close together , the spherical shock waves can coalesce into a cylindrical shock, providing an ionized channel.

The current trace and ultraviolet emission between 320 nm and 390 nm are given in Fig. 5 for a 9 cm laser initiated channel. An RLC analysis of the discharge, after accounting by short circuit measurements for the circuit parameters, yields a channel resistance of 0.14 ohms for a 9.5 cm length.

The observation that the 250 cm focal length mirror initiated and guided longer channels led to a further investigation concerning the scaling of discharge channel length with incident laser energy. These results , given in Fig. 6, indicate that the maximum channel length for reliable discharge initiation scales roughly linearly with incident laser energy. Also plotted in Fig. 6 is the total length of breakdown beads , as interpreted from the pattern on the open shutter photographs. Both curves tend to support the hypothesis that the laser induced breakdown generates an ionized chain which is capable of initiating and guiding discharges at voltages which are inadequate for sparkover without laser initiation. These results are also consistent with measurements of the total charge of laser generated ions versus laser power, reported in Ref. 4. It should be noted that with the delay time between laser induced breakdown and high voltage pulse of only 4 μs, a significant fraction of molecular ions should be present in

the gap. Since the charging voltage was held constant for the data of Fig. 6, the results also demonstrate that a tradeoff exists in laser power versus discharge voltage in terms of the maximum reproducible channel length.

The experiments using dual foci were designed to eliminate the problem of laser energy deposition in a single focal spot. By splitting the main laser beam into lower power beams and separately focusing these beams in series it should be possible to generate a longer chain of breakdown beads than would be possible with a single focus.[1]

Using the focusing configuration of Fig. 2c experiments were performed to demonstrate the difference between single and dual foci at lower laser power. Figure 3c illustrates the two distinct breakdown sparks which were generated with the dual foci at lower laser power levels. It was found that the dual foci provided slightly better guidance (Fig. 4d) although no significant difference in maximum channel lengths was found. This may have been due to the fact that the power which was split off from the main beam was inadequate for reliable optical breakdown of air.

An interesting observation which was made in the course of the investigation at lower laser power was the discovery of extremely long delay times between the application of voltage to the gap and the onset of current flow. During an experiment to compare the 79 cm focal length lens at lower power to the dual foci it was found that for both cases approximately 50% of the discharges occurred within 10 μs of

the high voltage pulse ; however, the remaining 50 % of the discharges occurred with delays ranging almost uniformly from 10 μs to 240 μs. These anomalously long delays have been shown in other experiments[10] to be characteristic of a very low overvoltage condition. The interpretation at this time is that a normally undervolted gap is caused to be slightly overvolted by the molecular ions generated by laser initiation. The long delay times are believed to be due to ion diffusion times required to close the gap.

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REFERENCES

1) W. K. Pendleton and A. H. Guenther, Rev. Sci. Inst., vol. 36, p 1546, 1965.

2) J. R. Greig, D. W. Koopman, R. F. Fernsler, R. E. Pechacek, I. M. Vitkovitsky, and A. W. Ali, Phys. Rev. Lett., Vol. 41, p 174, 1978.

3) D. W. Koopman, J. R. Greig, R. E. Pechacek, A. W. Ali, I.M. Vitkovitsky, and R. F. Fernsler, J. DePhysique 2077 Coll. 7, Suppl. 7, Tome 40 p 419,1979.

4) D. W. Koopman and K. A. Saum, J. Appl. Phys., Vol. 44, p. 5328, 1973.

5) K. A. Saum and D. W. Koopman, Phys. Fluids, Vol. 15, p 2077,1972.

6) G. Yonas, Sci. Amer., Vol. 239, p 50, 1978.

7) P.A. Miller, R. I. Butler, M. Cowan, J. R. Freeman, J. W. Poukey, T. P. Wright, and G. Yonas, Phys. Rev. Lett., Vol. 39, p 92,1977.

8) K. Imasaki, S. Miyamoto, T. Ozaki, H. Fujita, S. Nakai, and C. Yamanaka, J. Phys. Soc. Japan, Vol. 50, p 3847, 1981.

9) D. E. Lenicioni, Appl. Phys. Lett., vol. 23, p 12,1973.

10) F. Llewellyn-Jones, Ionization and Breakdown in Gases, John Wiley, New York, 1966, p 141.

FIGURE CAPTIONS

Figure 1. Experimental Configuration. The spark gap switch is triggered by a preset delay (typically 4 μs) following the laser pulse. A fan circulates lab air in the channel chamber.

Figure 2. Alternative focusing systems for initiation and guiding of discharge channels. The electrodes were constructed of thin brass plates and pointed screws to minimize interception of the beam.

a) Single focus with germanium meniscus lens,

b) Single focus with gold mirror, and

c) Dual foci configuration in which about 4% of incident laser power was split off the main beam by the salt wedge and focused to generate a breakdown spark in series with the breakdown generated by the germanium lens focus.

Figure 3. Open shutter photographs of laser induced breakdown using:

a) 79 cm focal length lens located to the right of the photo,

b) 250 cm focal length mirror located to the left of the photo,

c) Dual foci configuration of Figure 2c with lens and mirror located to the left of photo. Laser power in c) is lower than in a) and b).

Figure 4. Open shutter photographs of:

a) Discharge channel (3.2 cm length) without

laser initiation.

b) Laser initiated discharge channel (5.6 cm length) using 79 cm focal length lens located to the right of the photo.

c) Laser initiated discharge channel (10 cm length) using 250 cm focal length mirror located to the left of the photo.

d) Laser initiated discharge channel (3.2 cm length) using dual foci at lower laser power. Lens and mirror are located to the left of the photo.

Figure 5. Upper trace: channel current (10 kA/div, 5 μs/div) Lower trace: Ultraviolet emission (320-390 nm) from discharge channel (100 mv/div, 5 μs/div). Obtained using two UG-1 UV filters in series with photomultiplier tube. Flash from laser induced breakdown is visible 4 μs before discharge.

Figure 6. Data indicated by circles (O) represent laser initiated discharge channel length versus incident laser energy. Percentages denote the probability of discharge occurrence. Data points with x's represent sparkover of gap without laser initiation during a separate experimental run. Triangular points indicate length of light emission from laser induced air breakdown without high voltage, obtained from open shutter photographs.

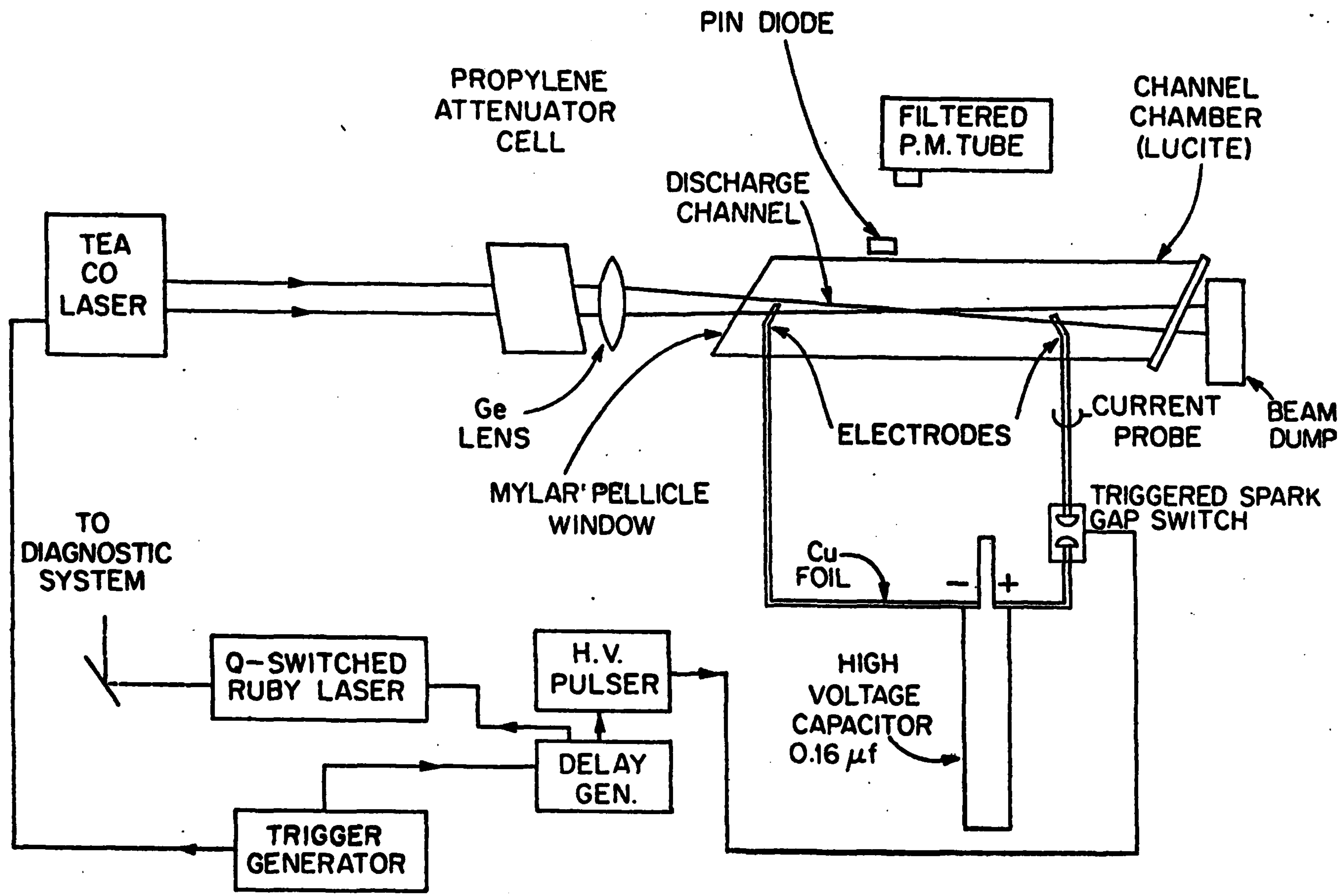

PIN DIODE
PROPYLENE ATTENUATOR CELL
FILTERED P.M. TUBE
CHANNEL CHAMBER (LUCITE)
DISCHARGE CHANNEL
TEA CO LASER
Ge LENS
MYLAR' PELLICLE WINDOW
ELECTRODES
CURRENT PROBE
BEAM DUMP
TRIGGERED SPARK GAP SWITCH
TO DIAGNOSTIC SYSTEM
Cu FOIL
–
+
Q–SWITCHED RUBY LASER
H.V. PULSER
HIGH VOLTAGE CAPACITOR 0.16 μf
DELAY GEN.
TRIGGER GENERATOR

Figure 1

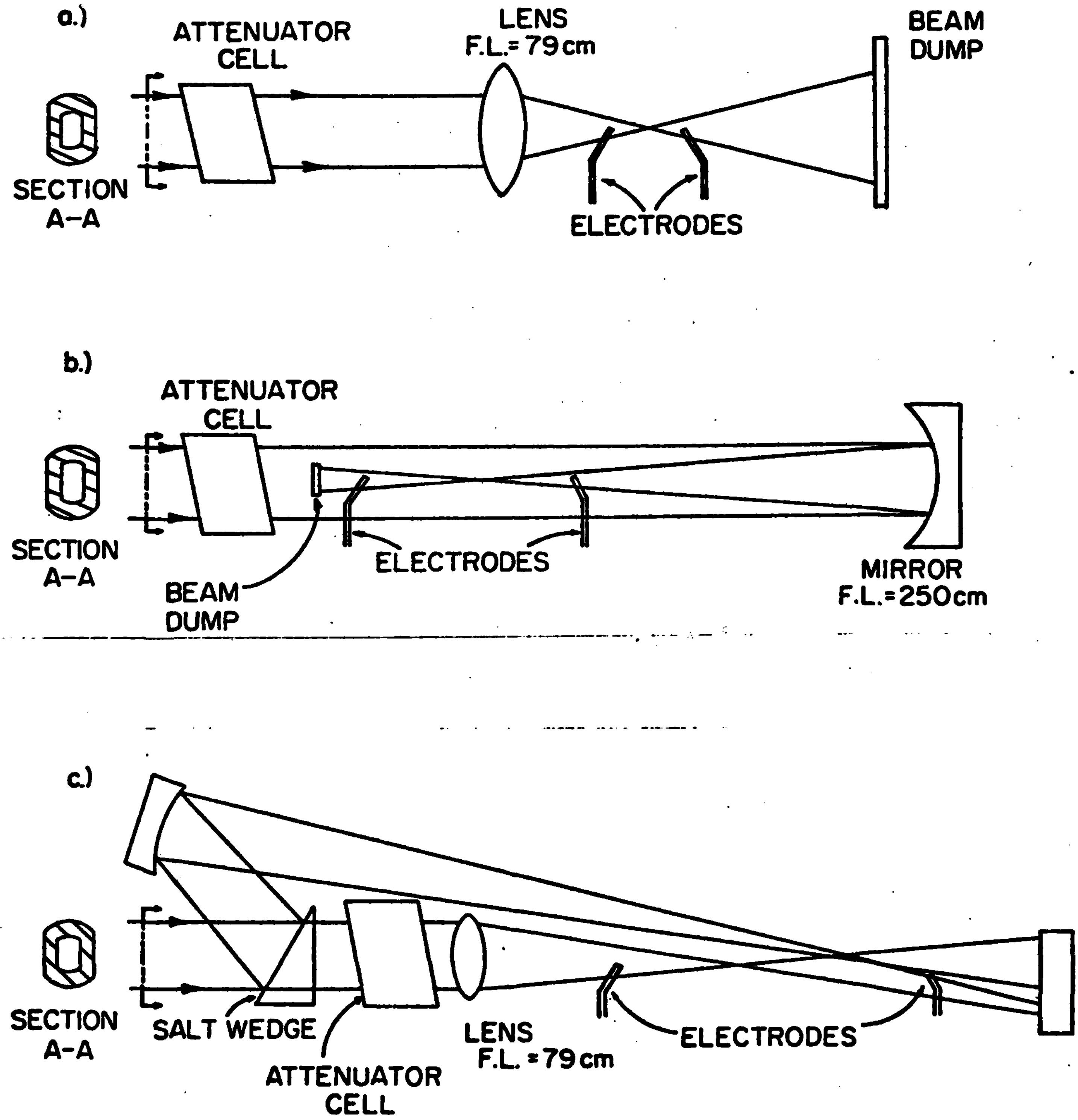

a.)
ATTENUATOR CELL
LENS F.L.= 79 cm
BEAM DUMP
SECTION A-A
ELECTRODES
b.)
ATTENUATOR CELL
SECTION A-A
BEAM DUMP
ELECTRODES
MIRROR F.L.=250 cm
c.)
SECTION A-A
SALT WEDGE
ATTENUATOR CELL
LENS F.L. = 79 cm
ELECTRODES

Figure 2

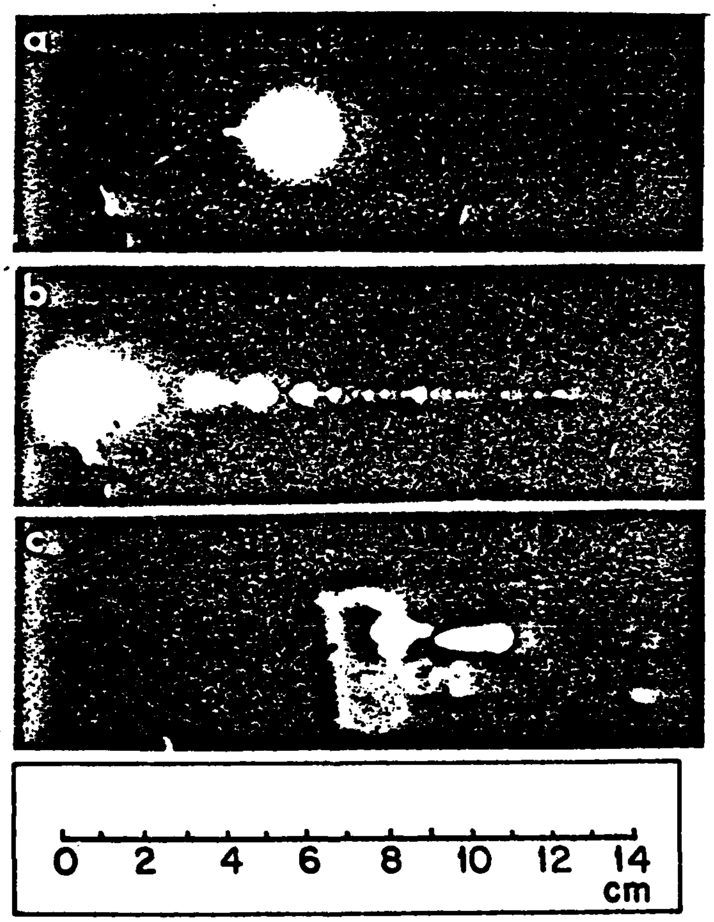


Figure 3

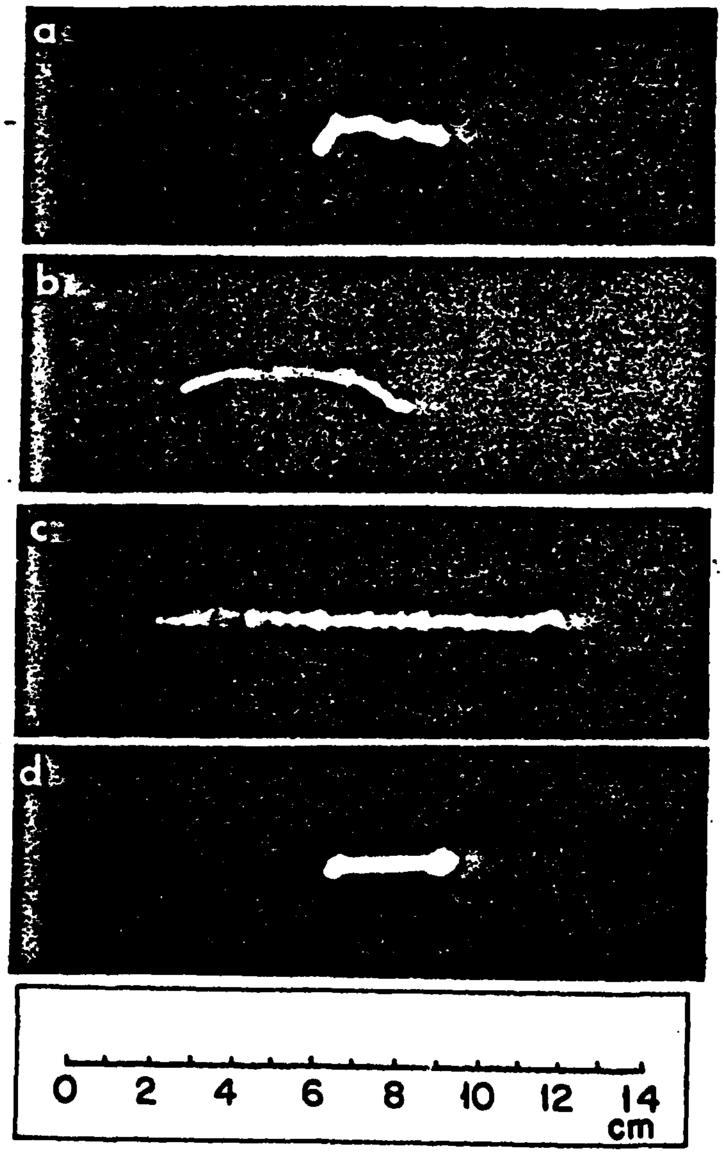


Figure 4

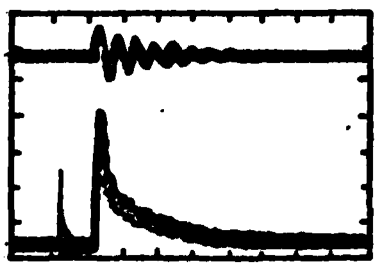
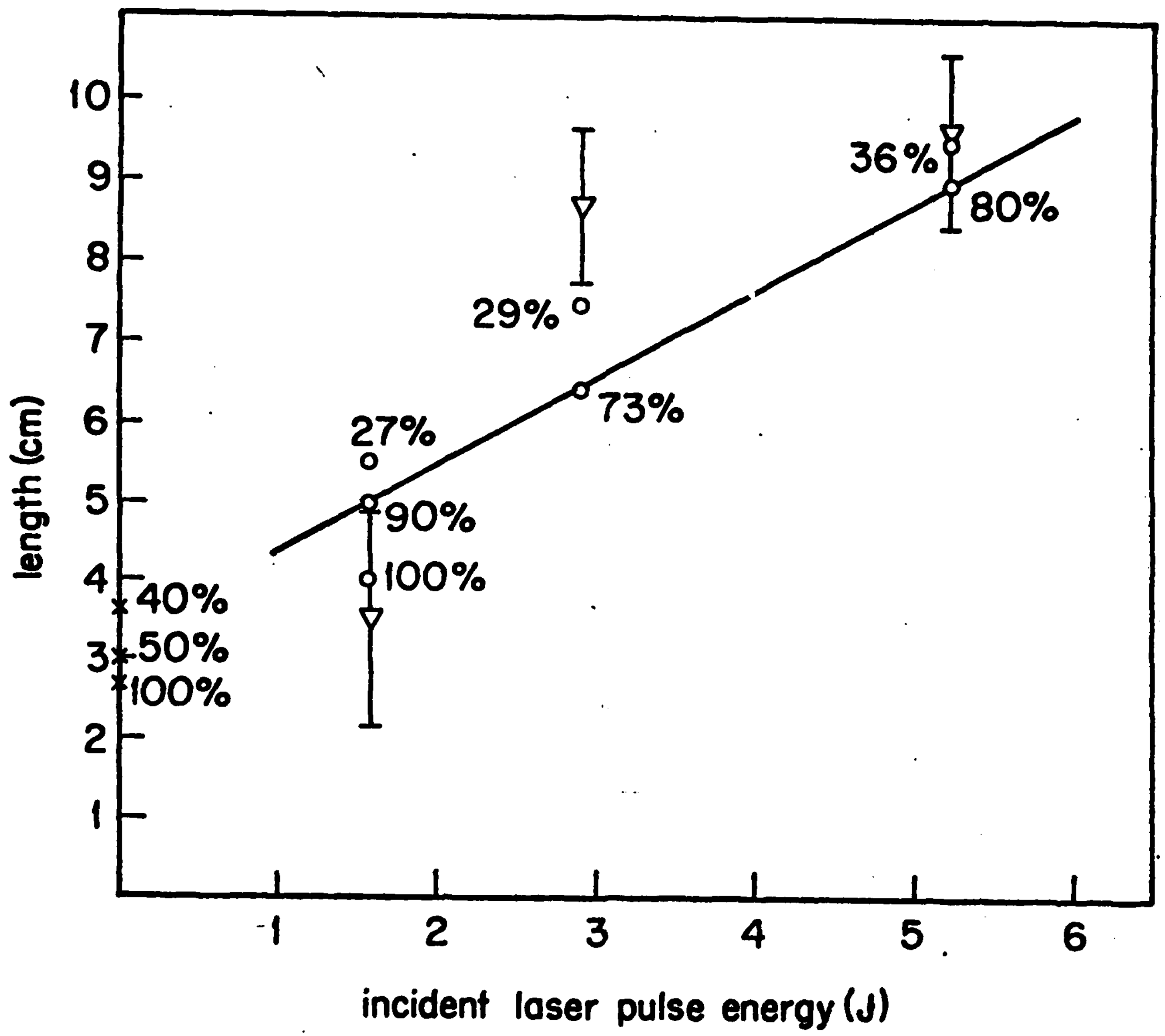


Figure 5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9
8
7
6
5
4
3
2
1
length (cm)
-1
2
3
4
5
6
incident laser pulse energy (J)
36%
80%
29%
73%
27%
90%
100%
40%
50%
100%

Figure 6

ME

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